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PROTOTYPE INSTRUMENTATION AND DESIGN STUDIES

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13. ABSTRACT *(Maximum 200 words)*

The Shuttle Potential and Return Electron Experiment (SPREE) was flown as part of the Tethered Satellite System (TSS-1) on STS-46 launched on July 31, 1992. A significant portion of this contract has been spent on the design and development of the SPREE analyzer system. The successful launch and operation of the SPREE during the TSS-1 and EOIM mission were the culmination of the past five years' work. This final report details the SPREE system as flown and some of the preliminary results. These successes include a real-time charging detection algorithm that correctly and accurately diagnosed the potential of the Shuttle with respect to the ambient plasma, a particle correlator system that was able to accurately detect and analyze wave/particle interactions triggered by electron beam operations, a pair of digital data recorders that archived 5 Gigabytes of data, two sets of triquadraspherical electrostatic analyzers that measured the flux of electrons and ions from 10 eV to 10 KeV and from 10^3 to 10^{14} particles/cm^2-ster-sec., and occasional operating pressures that exceeded 1×10^{-4} Torr.

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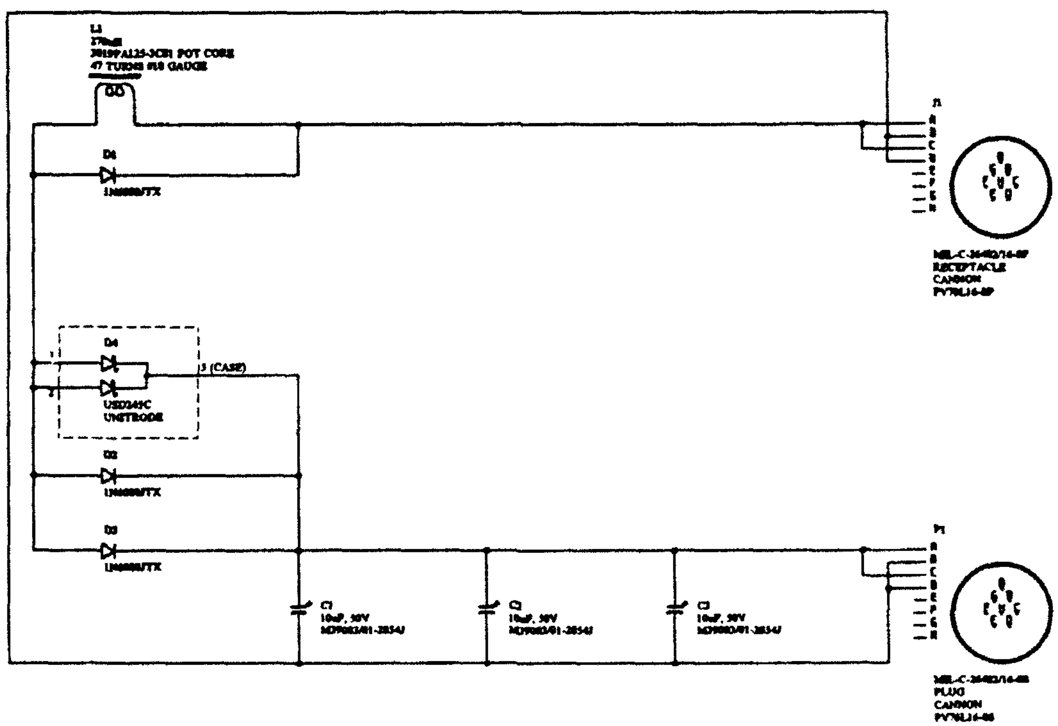
SPREE Power Filter for TSS-1

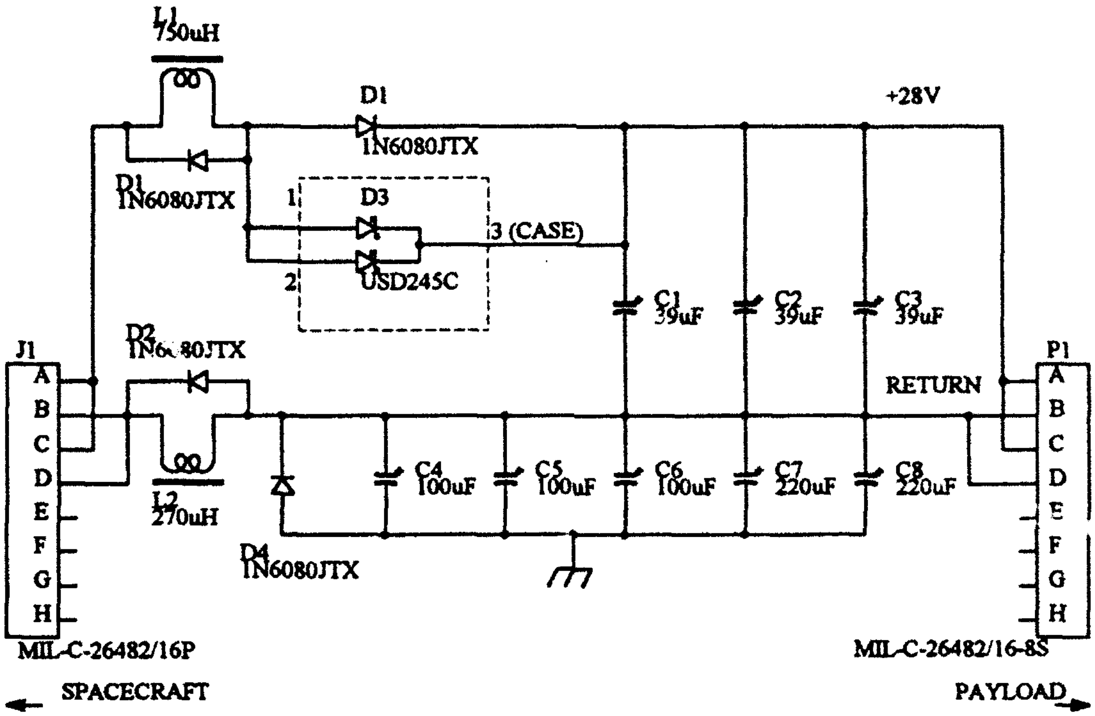
As integration and testing progressed at Kennedy Space Center (KSC), the need for additional power filtering became evident. Operation of the other MPESS experiments could cause resets to the SPREE DPU and occasional tape recorder errors. Additional filtering was designed, fabricated and installed on the SPREE power line. The additional filtering seemed to PROTECT THE spree SYSTEMS FROM RESET.

Amptek returned to KSC to complete the final electrical tests of the TSS-1 experiment before delivery to the launch pad. Much to everyone's surprise, the noise problems that had thought to be cured with the power filter and capacitor bank filter that had been added to the 28 volt feed line re-appeared. Since only days remained before the system had to be delivered to the launch pAD, an intensive trouble shooting effort was begun. Another Amptek engineer was flown to KSC to assist in the analysis and correction of the problem. Another team began to work around the clock at the Amptek facility, testing on the engineering unit of SPREE. A cause and solution was found for the power resets that were occurring with the SPREE DPU. The power filter was removed from under the thermal blankets and modified to incorporate the new changes.

The modified filter was vibration tested and reinstalled into the experiment. Extensive tests were conducted and no further problems were encountered. Schematics of the original filter and the revised circuit are included with this report.



SPREE Power Filter - Design 1



SPREE Power Filter - *Final Version*

These changes worked well during the STS-46 mission. No power glitches, recorder resets, or DPU resets occurred. Cycling and operating other major power users in the shuttle bay had no effect upon SPREE. We believe that this filter provided the necessary protection for this severe operating environment.

SPREE Anode Rework Results

After the initial delivery of SPREE to the Kennedy Spaceflight Center (KSC), the Electrostatic Analyzers (ESAs) were returned to Amptek for further work in an attempt to reduce the noise seen by some angular zones. Earlier reports detailed these noise reduction efforts which resulted in reducing the size of the angular zones to avoid charge collection near the edges of the microchannel plates. These changes were made and the instrument was calibrated. Noise was much improved, but still evident. As time ran out, we re-delivered the ESAs to KSC.

These analyzers then sat at KSC for more than a year without ever being under vacuum or the microchannel plates being powered. Forty-eight hours after launch, power, including high voltage to the microchannel plates, was applied. After a very brief period of slight noise counts, the instrument performed flawlessly with respect to noise counts. No large noise bursts of any sort were observed throughout the Shuttle mission. The earlier efforts

at noise reduction had been successful and the use of a microchannel plate based instrument on Shuttle without requiring continuous gas purge or vacuum sealing had been demonstrated.

It is interesting to note that Amptek is designing a new instrument using microchannel plates and has obtained a bid on these plates from the same manufacturer (Galileo Electro-Optics). We noticed that part of the product specification consisted of a new warning that laser cut microchannel plates may have increased noise counts near their cut edges. We asked the manufacturer why we had not been told this on our earlier order, and they told us that we were the first laser cut microchannel plates that they had processed. They only discovered the problem after our order was completed and delivered.

Published or submitted Papers

Two papers have been written on the SPREE experiment. One paper focused on the nested triquadrispheric electrostatic analyzer and was submitted to the Review of Scientific Instruments. That paper was published in March 1992 under the title "*Compact ion/electron analyzer for spaceflight or laboratory use*". That paper is reproduced in Appendix I of this report.

The other paper was submitted to an IEEE journal where it was first referred to a different journal and then rejected on the basis that it described an instrument that had not flown. Now that the system has flown, we intend to update the paper with illustrations of the results of various measurement and processing techniques. Appendix II contains this paper.

Updated Charge Algorithm and Functional Results

The charging algorithm operated on SPREE was a first of its kind. It processed real time data and derived a real time charging detection and measurement that was downlinked to the ground and displayed on the aft flight deck for the astronauts' information. Earlier reports described the structure of the program and may be referred to for details. For the purposes of this report, we provide a description of the rationale and philosophy of the algorithm.

One of the objectives of the Shuttle Potential And Return Electron Experiment (SPREE) is to determine the Space Shuttle's potential relative to the surrounding plasma.

A spacecraft at elevated potential will attract ions or electrons in an attempt to neutralize its charge. An Electrostatic Analyzer (ESA) that records the velocity (energies) of the attracted particles can determine the spacecraft's relative potential. The following algorithm attempts to determine the Space Shuttle's potential from data collected by the twenty ion zones in the SPREE ESAs.

A negative charging event should produce a peak in the ion energy spectrum. A simple algorithm could search all the elevation zones for the energy with the greatest count and assume that it represents the potential. However, multiple peaks, background noise, and saturation could fool such a routine. A complete program must be able to ignore situation

that do not indicate charging. The SPREE algorithm uses several functions to process data, producing a potential determination with an associated confidence factor.

The unknown plasma interactions during the tether experiment posed a challenge to the instrument designers. Various parameters of the charging algorithm might need modification on orbit to properly predict charging events. Uplink capability to the microprocessor code was provided to alter key variables. SPREE was also been pre-programmed with default parameters derived from calibration tests.

Some of the algorithm commands include:

- - limit the maximum flux that the algorithm should consider valid.
- - indicate sensor saturation levels that should be ignored.
- - set the minimum threshold necessary for a valid peak.
- - mask noisy or malfunctioning channels.
- - select reporting between the most intense or the most frequent peak.
- - transmit test and calibration data.

The algorithm functions by absorbing all the ion data that the sensors can produce and sifting the information down to its most noteworthy components. Selected knowledge gained from the algorithm is stored and a confidence factor is derived from the decision making process. The confidence factor is weighted on a scale from 0% to 100% and represents the best estimate of the validity of the potential reported.

Every second, the auxiliary processor starts a new algorithm routine. Parameter values are copied from the default table. The processor then acquires 20 complete spectra from the analyzers during a single high voltage sweep. The data are scanned for possible saturation conditions and then the data set is filtered. Most of the information can be compressed by eliminating all but the important peaks. All data points can be eliminated that have a larger adjacent point. Other points that can be ignored are those greater than the saturation level, less than the threshold, and those at the beginning and the end of the energy sweep. The largest remaining value is called the primary peak, the next largest the secondary peak. The azimuth, elevation, and count rate for these peaks are recorded.

The algorithm further records as many high voltage sweeps as are necessary for one second, one sweep in slow mode and eight sweeps in fast mode. A tally of all sweeps is analyzed and a report is generated. The report includes information on the peak flux, its azimuth and elevation, the average flux for that elevation, and the ion and electron spectra for the zone that contained the peak.

After the data has been tallied, a confidence factor is determined. This algorithm weighs the following in consideration:

- - The number of analyzers providing data.
- - Whether the rotary tables were scanning.
- - If a peak was detected.
- - Whether the peak was determined by its high count or its periodicity.
- - The magnitude of the primary peak compared to the secondary peak.
- - If the potential determined was within the limits expected.

- - The FWHM of the peak
- - The number and location of saturated energy measurements.
- - The extent of masking of certain channels.

The confidence factor is tagged onto the end of the potential determination report and is sent to the primary processor through a memory mapped mail box. Astronauts and ground support personnel have access to a powerful real-time plasma diagnostic tool that assists in determining charging events and provides the specific to support its result.

SPACE Results

SPACE type particle correlators have been flown on previous spacecraft such as the CRRES satellite and have been successful. The TSS-1 mission was a particularly good scenario for demonstrating the technique. The presence of electron guns plus the expected current and voltage that a long conductive tether induced were conditions certain to produce a variety of plasma densities and stimulate the natural environment. An earlier report, "*Empirical Techniques for the Study of Acceleration Mechanisms in the Space Environment*"* described some of the physical mechanisms involved in these processes and described some of the effects that we hoped to measure on TSS-1. We have excerpted below a few paragraphs of that report which describe the three methods used by the SPREE SPACE experiment to detect wave/particle interactions.

High Frequency Buncher Mode

> "Electrons are expected to undergo interactions with waves at frequencies in the range of 1-10 MHz. The local electron gyro frequency, ≈1.4 MHz, the local upper hybrid frequency, 1-7 MHz, and lower harmonics of these frequencies are the wave sources. These high frequency modulations are superimposed on counting rates that are anticipated to be of the order of 100,000 counts per second or less. A one bit "buncher" mode of correlation can be used to de-convolve high frequency data from these counting statistics. The time of arrival between successive electrons can be measured by a 20 MHz clock. A histogram of the number of measured separations as a function of separation units (50 nS) can be accumulated over a period of time. This is the equivalent of averaging many one bit correlation functions, each with only two bits set. This technique has been used successfully to identify modulations at

* J. McGarity, A. Huber, and J. Pantazis, "Empirical Techniques for the Study of Acceleration Mechanisms in the Space Environment", PL-TR-91-2273 Final Report for Phillips Laboratory, Hanscom AFB, MA 01730, (1991) ADA260031

Megahertz frequencies present on the natural auroral beams above auroral arcs.[1]

To accommodate the expected wide range of counting rates and still perform some meaningful correlations in reasonable time and space, the high frequency range should be sub-divided into three frequency regimes, 0-.625 MHz, 0-2.5 MHz, and 0-10 MHz. This can be accomplished by selection of various multiples of the clock units to create a histogram.

Six electron channels are correlated at a time. All of the 20 electron channels and all three of the frequency bandwidths can be commutated through the correlation process every nine minutes."

The high frequency buncher mode worked quite well on SPREE. We did indeed see count rates in excess of 100,000 per second. We were able to measure the local gyro frequency even in ambient conditions and the results correlated quite well with standard altitude/density tables. We also saw some interesting wave/particle interactions in some of the data.

Low Frequency Auto-Correlation Function

"Low frequency auto-correlations can be performed in the frequency band from 0 to 10 kHz. This frequency range contains the lower hybrid frequency and the ion gyro frequencies (<1 kHz). Naturally occurring modulations at these frequencies are expected both in ions and electrons.

Twelve independent simultaneous auto-correlations may be performed by twelve 80C31 micro controller units (MCU). A commutation system would allow these MCUs to process all forty data channels (20 ion and 20 electron) using three different bandwidths: 0-10 kHz, 0-5 kHz, and 0-1.3 kHz. The modulation detection efficiency for such a system would range from 72% with the 10 kHz bandwidth to 99% for the 5 and 1.3 kHz bands. The 80C31 MCUs can be controlled by a dedicated 80C86 which will supervise all of the SPACE operations and communicate with the rest of the SPREE via a "mail box" scheme in shared memory."

The low frequency auto-correlation also worked. We were able to detect both the lower hybrid frequency and the ion gyro frequency. Data analysis is being performed by our British co-investigator, Dr. Paul Gough. With 4 Gigabytes of data, it will be some time before a complete picture of the mission is available.

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[1]M. P. Gough, P. J. Christiansen, and K. Wilhelm, "Auroral Beam-Plasma Interactions: Particle Correlator Investigations", J. Geophys. Res. 95,(1990)

Beam Cross Correlation

> "Part of the TSS-1 mission consists of electron guns used to inject the tether current collected from the satellite back into the local ionosphere at the Shuttle end. These electron beams can be actively modulated at kilohertz frequencies which will in effect "tag" the beam electrons with this artificial frequency. Depending on frequency and plasma conditions, the modulated beam may trigger natural emissions. Any portion of the electron beam returned to the shuttle can be identified from its known frequency signature. Furthermore, any beam electrons that have undergone acceleration or deceleration, or natural electrons which have interacted with the beam modulation can be identified by the correlator.
>
> Both electron gun systems that will operate during the TSS-1 mission can provide synchronization signals to the SPACE instrument so that it will know when a gun is emitting. For each channel analyzed, counts are binned into two counters depending on whether the electron guns are on or off. A separate count of a stable oscillator provides a measure of the total time spent on or off. If there is no significant modulation present in the accumulated counts, then the variation of these two sums should be of the order of that expected of Poisson statistics taking into account the different total times spent in the two states. This will give a direct measure of the significance of any modulation present in the particles at the beam modulation frequency."

The beam cross correlation mode proved to be one of the most useful SPACE modes. Because of the deployer problems, much of the mission was spent in joint flight objectives between the SETS electron guns and SPREE. We saw the beam return to the shuttle under some conditions. We could see modulations of the electron beam inducing both damping and enhancements to the plasma frequencies.

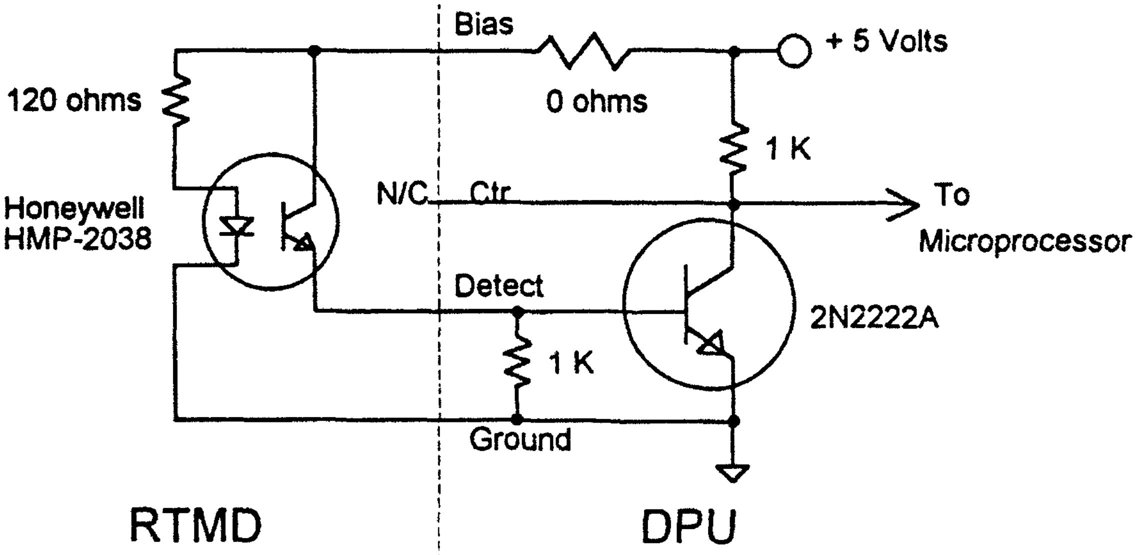
The SPACE experiment stored almost all of its data on the on-board recorders. A neural network algorithm devised by Dr. Gough to function as an "intelligent" data analyst monitored the SPACE operations and was inserted in the real time telemetry. It was the only real time telemetry visibility that SPACE had. It worked quite well throughout the flight. It reported frequent significant correlations resulting from various flight objective operations. The limited amount of post flight data analysis that has been performed has verified the accuracy and usefulness of this technique.

RTMD Problem

The only problem that was observed on SPREE was an erratic position indication that affected RTMD-B on most passes through orbital noon. The error seemed to occur after the shuttle had been in sun light for 20 minutes or so. The A motor system would appear to detect its 270° point prematurely by about 10°. This in turn would cause the DPU to attempt to resynchronize the rotary tables. If B was stopped from rotating, the A table seemed fine. The problem would continue even into the dark portion of an orbit, but would correct itself after approximately 10 minutes of dark. The correlation between day

and night indicate the problem was either triggered by ambient light or a thermal change. The hysteresis with respect to the terminator indicate that it probably was temperature related.

The position detection circuit, as flown, is drawn below. The Honeywell photo sensor was located on the outer wall of the RTMDs and the buffer transistor was contained on a board inside the DPU. The interconnections went through several electrical plug interfaces between the DPU and Honeywell sensor. These interconnections have been left off to simplify the circuit.



This circuit allows ~30 mA LED current. The HMP-2038 data sheet gives min/max photo transistor current of 2 to 10 mA which should be accommodated by the base of the 2N2222A receiver. Sensor dark current under these circumstances is <100 μa and the false trigger point would be 600 μa. All of these numbers are contingent on proper reflector spacing and cover the entire rated temperature (-40° to +100°C) of the optosensor. Since these numbers imply that the sensor will operate properly as designed, and the duplicate circuit in RTMD-A functioned properly, we conclude that the spacing between the sensor and reflector was not correct. This could have occurred due to vibration or poor installation. Further diagnosis will have to await return of the hardware.

Appendix I "*Compact ion/electron analyzer for spaceflight or laboratory use*"

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Compact ion/electron analyzer for spaceflight or laboratory use

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A space qualified 260° spherical plate electrostatic analyzer has been developed as a plasma diagnostic tool. The use of nested spheres and unusually shaped microchannel plates has resulted in a sensor capable of measuring simultaneously the three-dimensional populations of ions and electrons in a plasma. High-current microchannel plates and a new packaging of a hybrid preamplifier discriminator are combined with an uncommon high-voltage circuit. The combination of these features yields an analyzer that is compact and lightweight, efficient in its power consumption, and has a broad dynamic range.

I. INTRODUCTION

Passive and active experiments both in laboratory and in space routinely require the determination of the angular and energy characteristics of electrons and ions in the energy range from ~ 10 eV to 10 keV. In this paper we report on the design of a new compact detector to make such measurements with a flexibility to operate over a wide dynamic range in particle fluxes. The instrument described has been developed as part of diagnostic equipment for the Electrodynamic Tethered Satellite Program (TSS-1).[1] In TSS-1 a satellite will be deployed from the Shuttle to a distance of 20 km using a conducting tether.[2] In the deployed system a potential of up to 5 kV will be generated between the satellite and the Shuttle. This potential will be used to drive a current down the tether to the Shuttle. This current will then be completed into space using kilovolt and multikilovolt electron beam systems.[3,4]

The detector developed was designed to measure the level of negative spacecraft charging produced by any of the tether current flowing or leaking to the Shuttle ground. Additionally, it has the capability to characterize any electrons from the beam systems that return to the Shuttle and any heating or other perturbations to the ambient plasma environment produced by the operation of the beams. This active regime required an instrument capable of operating over a wide dynamic range with good rejection characteristics for particles scattering.

The analyzer design evolved from earlier work published by Johnstone *et al.*[5] Several changes were made to accommodate the TSS-1 mission. These changes were (a) nesting two sets of triquadrispheres for energy/angle discrimination to allow, in a single sensor unit, for both electrons and ions to be measured simultaneously over an angular fan of 100° (the instrument has an intrinsic capability to measure angular position in the fan to an accuracy of 1°, but for the present instrument the 100° fan was segmented into ten 10° sections), (b) to minimize fringing field distortion, the triquadrispheric deflection plates were assembled as continuous units and mounted to avoid plate nonconcentricity; there was no particle stop or aperture at the 180° position between the plates, (c) a specially shaped high current, low-noise microchannel plate was used for particle detection, and (d) an improved high-voltage circuit was used to bias the microchannel plates (MCPs) and provide 32 voltage steps for an energy sweep from 10 eV to 10 keV. The analyzers were mounted on rotary tables such that all angles out of the shuttle bay will be viewed by the detectors.

II. NESTED SPHERES

A nested sphere geometry was chosen since this approach would be compact and could perform electron and ion analysis simultaneously in the same flux interval. Both energy and angular measurements would be tightly coupled and could be well defined by preflight calibrations. Four 260° spherical plates were nested inside each other and electrically combined in pairs that selected either electrons or ions.

Due to an electron's smaller mass and greater mobility, electron fluxes are anticipated to be greater than ion fluxes. For this reason, the inner set of spheres was designed for the measurement of electrons since their smaller size would tend toward lower sensitivity. The polarity of the voltage on the outer pair of spheres was set to measure positive ions.

To avoid electric field breakdown all sharp edges were eliminated between high-voltage conductors. The potential applied in vacuum across adjacent conductors was limited to <3000 V per millimeter. The potential across a dielectric surface was limited to <1000 V per millimeter. Kel-F was used to position the spheres and mount the deflection plate assembly. These design rules helped establish minimum plate spacing.

The deflection plates were constructed using spun aluminum hemispheres. Aluminum bands were used to mate the 80° segments to the 180° hemispheres. The gap between plates where charged particles are processed was kept clear of any materials, conductive, or otherwise. The spherical plates were assembled together by attachment to the mounting rings. Care was taken to ensure that the spheres were positioned concentrically to ensure a uniform radial electric field. The deflection plates were bead blasted,

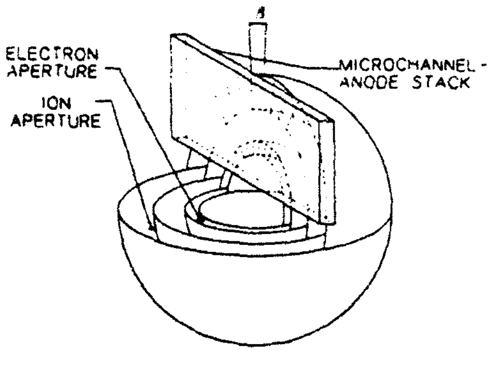

FIG. 1. Schematic of the nested spheres, inlet apertures, and post-analysis detector assembly.

chemically etched, and plated using a chromate conversion process to prevent oxidation and improve their spurious particle rejection characteristics. Wire leads for the deflection voltages were attached using conductive epoxy. Figure 1 illustrates our use of the nested spheres.

The approximate geometric factor for a triquadrisphere can be calculated from its dimensions.[6-8] The geometric factor of an instrument is a measure of its sensitivity and can include detection efficiency as well as energy bandwidth. For the purposes of this paper the geometric factor consists of the area of the aperture times the viewing solid angle. The maximum circular aperture for a given set of spherical deflection plates will be the separation (ΔR) between them. The solid angle consists of the product of the unfocused angle β (determined by the anode shape) and the focused angle α (determined by the plate separation). These dimensions are listed in Table I. An analyzer constant (k) relates deflection plate voltages to the transmitted or selected particle energy.

$$k = \frac{1}{\ln(R_0/R_i)}. \tag{1}$$

The maximum energy band pass of the system ($\Delta E/E$) may be approximated by

$$\frac{\Delta E}{E} \simeq \frac{(R_0 - R_i)}{(R_0 + R_i)} = \frac{\Delta R}{2\,R}, \tag{2}$$

where R_o and R_i are the radii of the outer and inner deflection plates being modeled, E is the center energy of singly ionized particles in the transmitted energy spectra, and ΔR is the separation between the pair of plates. The ratio of plate voltages necessary to place the zero potential surface at $\bar{R}$ [where $\bar{R} = (R_0 + R_i)/2$] is

$$-(V_0/V_i) = (R_i/R_0). \tag{3}$$

Finally, the geometric factor of the system can be estimated from

$$GF = (\pi d^2/4)\alpha\beta. \tag{4}$$

This results in maximum geometric factor for the electrons and ions of 1.36×10^{-2} and 1.16×10^{-1} cm^2/sr with $\Delta E/E$ of 11.1% and 14.8%, respectively. For use on the TSS-1 these geometric factors were reduced by the use of small aperture sizes to values of 3.3×10^{-5} and 3.1×10^{-7} cm^2/sr and 1.0×10^{-4} and 6.5×10^{-7} cm^2/sr for the two electron and ion sensors, respectively.

The 260° deflection system may be considered as two separate parts: a hemispherical electrostatic analyzer which selects particles for detection in a narrow energy band, followed by a quadrispherical electrostatic analyzer which acts principally to disperse the particles in position along the surface of the microchannel plate according to their input angle at the front aperture. Energy analysis and angular dispersion can be achieved with a single quadrispherical element but the use of a separate hemispherical electrostatic analyzer produces a nearly "rectangular" response in energy and angle. This in turn provides a more accurate representation of the input particle distribution function. The spacing of the analyzer plates limits particle access to an angular fan of ~7° in the spin plane. While the analyzer is intrinsically capable of a field of view of almost 180°, to avoid edge effects the field of view has been limited to 100° by the anode structure which collects charge from the microchannel plates.

The separation of the concentric spherical plates in the analyzer and the dimensions of the entrance aperture define an energy pass band. The central energy of that pass band is established by the electric field between the plates. Particles that gain access to the space between the plates are accelerated by the radial electric field. If the deviation in the particle trajectory produced by the acceleration is such that the particles follow great circle paths, they will travel through the space between the plates without collision. Such trajectories are focused after turning 260° such that each particle's angle of incidence at the entrance aperture is imaged onto the microchannel plate to an accuracy of ~1°.

III. DETECTOR/AMPLIFIER ASSEMBLY

Electrons and ions that follow great circle trajectories through the interplate space are detected by using microchannel plates as electron multipliers and a conductive anode system to collect the microchannel plate output charge. The detector assembly must be thin to avoid ob-

TABLE I. Dimensional parameters of the nested spheres and the calculated performance of the system.

	R_0 (cm)	R_i (cm)	ΔR (cm)	$\bar{R}$ (cm)	k	$\Delta E/E$	2α (Radians)	β (Radians)	Geometric Factor
Ions	5.833	4.328	1.505	5.08	3.375	14.81%	0.3728	0.1745	1.16E-01 cm²/ster
Electrons	2.978	2.384	0.594	2.681	4.511	11.08%	0.2803	0.1745	1.36E-02 cm²/ster

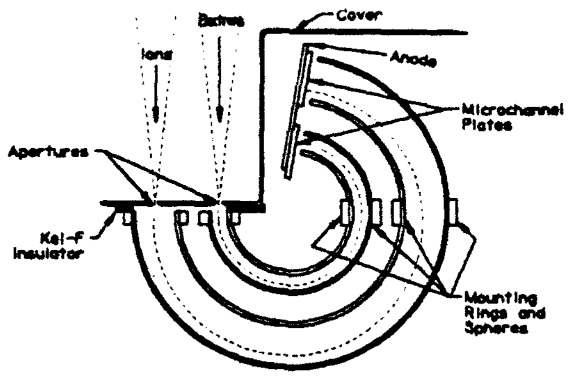

FIG. 2. Schematic cross section of 260° spherical plate electrostatic analyzer.

scuring the input field of view. Figure 2 shows a cross section of the assembly.

Low-energy particles must be accelerated to a few hundred eV before the microchannel plate can efficiently detect them. A highly transmissible ground screen is mounted across the exit region of the deflection plates. The input side of the ion MCP is biased to -2100 V and the output side placed at -100 V. The ion anode surface is directly coupled to the preamplifiers and is operated at virtual ground. The electron MCP input side is biased to $+400$ V and the output side is operated at $+2400$ V. The electron anode surface is biased to $+2500$ V and capacitively coupled to the preamplifiers. This configuration provides predetection acceleration potentials to incoming particles and the 2000 V bias necessary for the MCPs. It also provides a post-multiplier acceleration of 100 V for the charge cloud emitted from the MCPs to ensure efficient collection by the anode sectors.

Because the ion and electron MCPs are biased differently, there must be separate MCP assemblies. The ion MCP assembly requires a much larger collection area to match the dimensions of the outer sphere set. Rather than purchase two differently shaped large surface MCPs, a trapezoidal shape was designed that required two MCPs to map the ion channels and one to map the electron channels. Each trapezoid MCP set could be used for either ion or electron detection. Galileo Electro-Optics fabricated the special MCPs using a high strip current material and 25 μm pores at an 8° bias angle. Matched chevron pairs are assembled in direct contact with each other. The MCP gain at 2000 V bias is $\sim 5\times 10^6$. Figure 3 shows the MCP/Anode assembly.

The anode is divided into ten 10° sectors, for both ions and electrons, resulting in a 100° field of view for each species. The sphere and anode assembly is mounted at a 40° angle such that one of the edges of the 100° fan is parallel to mounting surface of the instrument and the other edge views 10° past its own zenith. The two sensors are mounted back to back on rotating platforms that sweep their viewing fans through 180°. This ensures that the two detectors sweep out a full 2π field of view. Figure 4 shows the assembled sensor and its field of view.

The 20 angular sectors in each analyzer use Amptek

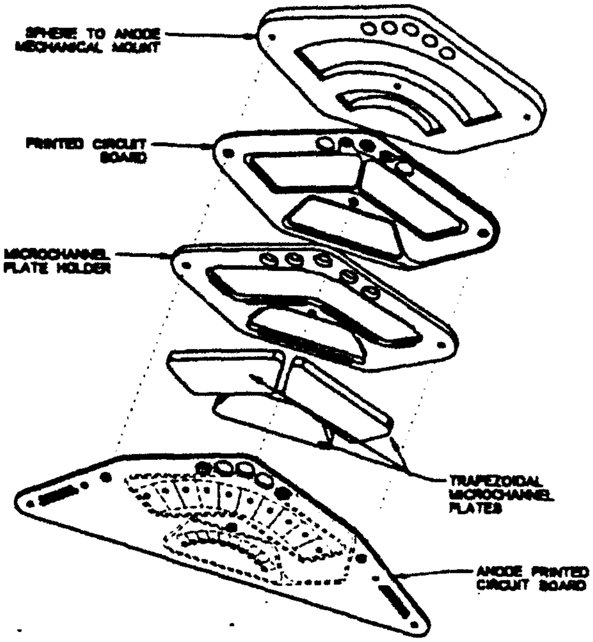

FIG. 3. Exploded view of the microchannel plates, holders, mounts, and anode assembly.

A111F PADs (preamplifier/discriminator) to convert the charge pulses collected from the anodes into logic pulses that may be counted and processed. The "*F*" version of the A111 is a flat pack assembly that allows very dense packaging of the electronics.

IV. HIGH-VOLTAGE GENERATION AND CONTROL

Bias voltage of ± 2500 V @ 100 μA each are needed to accommodate the high electrical current MCPs. Four stepped or swept voltages are required for the deflection plate potentials of up to 3400 and 2500 V for ions and electrons, respectively. A schematic for the high-voltage

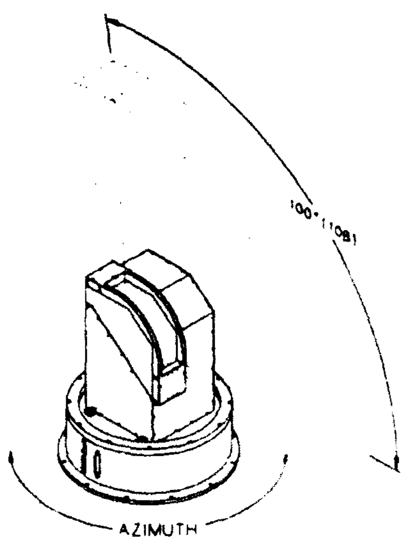

FIG. 4. Field of view of the electrostatic analyzer mounted on rotary table.

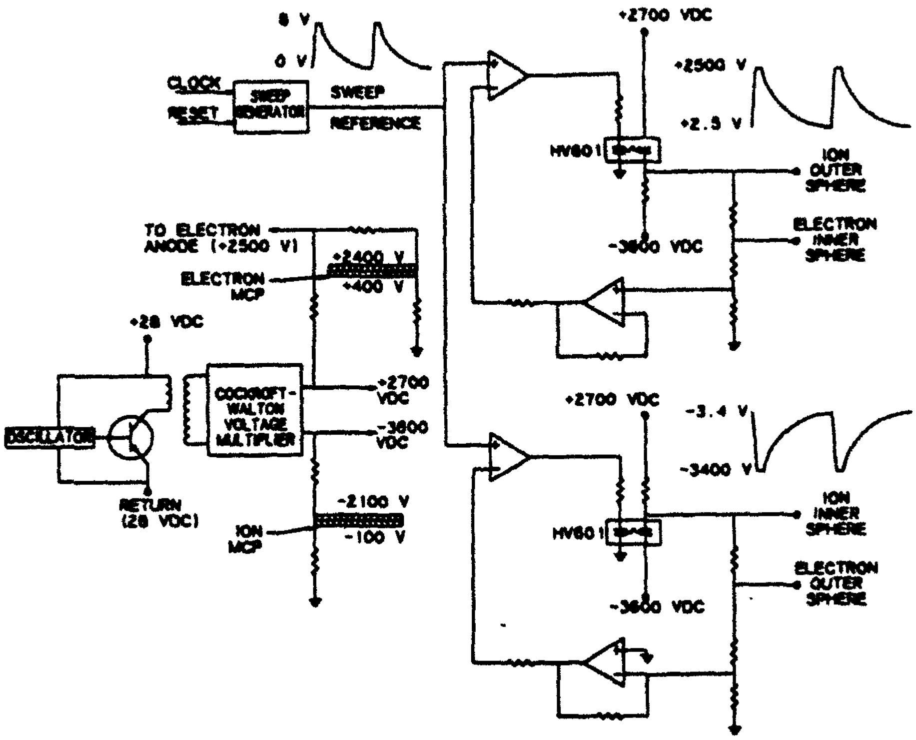

FIG. 5. Block diagram of the high-voltage circuitry. This circuit develops and controls both the microchannel bias potentials and the sweeping deflection voltages.

supply is shown in Fig. 5. To generate these voltages, an oscillator powered by a 28-V bus was constructed. A step-up transformer uses the oscillator output to drive the input of a pair of Cockroft–Walton voltage multipliers. The filtered multiplier output is shared by the MCP bias network and a bi-polar high-voltage sweep circuit. The sweep circuit uses a pair of Amptek HV601 high-voltage optocoupler to maintain the deflection plate voltages to values regulated by the sweep reference circuit. The sweep reference circuit is a logarithmic digital-to-analog converter that produces a 0–8 V output in 32 steps controlled by a clock signal and a reset command. The sweep regulator can be "parked" at a particular step or swept at either one or eight times per second.

V. CALIBRATION AND TESTING

Calibration and testing of the sensors was performed at the Geophysics Directorate, Phillips Laboratory at Hanscom AFB, MA (formerly Air Force Geophysics Laboratory). The units were successfully flight qualified for Space Shuttle use by testing vibration and thermal vacuum characteristics. Ion and electron calibration was performed using the energetic particle calibration facility[9] which has been upgraded to include a stable monoenergetic ion source.

To calibrate the ESAs, a measurement of their response to a known source of energetic particles is made. From these measurements, the energy pass band, angular response, energy-dependent geometric factors, and energy-independent geometric factors are calculated. In this calibration process, a sample of energies representative of the ESA's 32 point spectrum was selected to be scanned. These energies were 27, 44, 88, 141, 220, 275, 440, 682, 1070, 2100, 4050, 6330, and 10 050 eV.

Peak response for the electron detectors was measured at 276 eV. Adjusting for the 400 V post acceleration yields a peak efficiency at ~700 eV. Figure 6 shows a typical

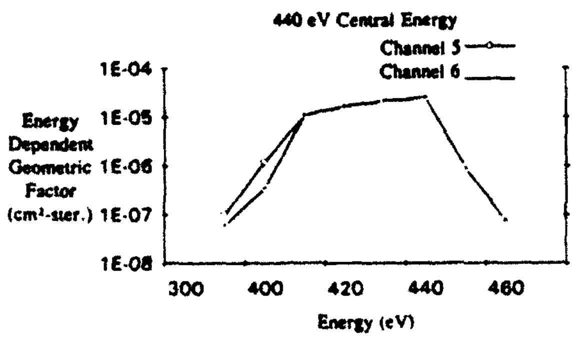

FIG. 6. Energy-dependent response curves for two electron channels. These response were from angles nearly normal to the aperture plane.

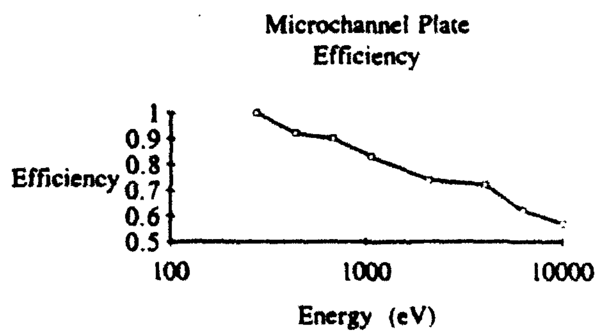

FIG. 7. Instrument detection efficiency as a function of electron energy.

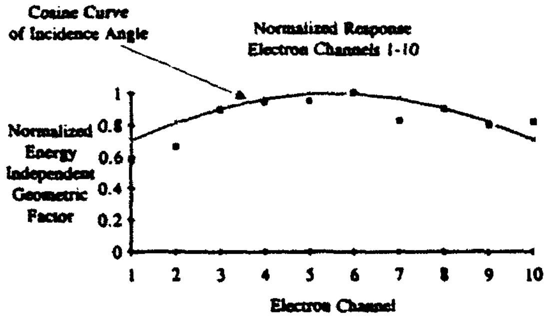

FIG. 8. Response of all ten electron channels showing the effect of cosine aperture shadowing as incidence angle increases.

example of the energy dependent geometric factor for the electron detectors while Fig. 7 shows the linear decrease in peak detection efficiency with increase in the measured energy. The plots of peak energy-dependent geometric factors indicate an approximately cosine fall off towards the edges of the detection view due to the decrease in effective detector collecting area (see Fig. 8).

Additional testing was performed in a plasma chamber where the sensors were installed in flight configuration (mounting bracket, rotary tables, data processing unit, and recorders as well as the sensors) and operated with an active plasma source and an electron beam. Using electron beam energies up to 1.8 keV and collected currents >20 mA along with plasma densities $>10^{15}/cm^3$ at pressures up to 2×10^{-4} Torr, an environment was created to simulate worst case scenarios of the TSS-1 environment. The sensor was biased to various floating potentials to simulate the Shuttle charging process. The output from the sensors remained coherent and, properly processed, correctly diagnosed the charge state of the carrier. The necessary dynamic range, noise immunity, and spurious particle rejection were demonstrated.

ACKNOWLEDGMENTS

The design of the nested spherical ESA was the direct descendant of earlier designs by Dr. Alan Johnstone and colleagues of the Mullard Space Science Laboratory in the United Kingdom. His generous sharing of notes provided the seed that eventually grew to the sensor system described above. Much of this work was sponsored by an United States Air Force contract No. F19628-87-C-0094.

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[3] P. R. Williamson, P. M. Banks, and W. J. Raitt, "Shuttle Electrodynamic Tether System," Space Tethers for Science in the Space Station ERA, Società Italiana di Fisca, Conference Proceedings No. 14, 1988.

[4] C. Bonifazi, P. Musi, G. Cirri, and M. Cavallini, "TSS Core Equipment: A High Perveance Electron Generator for the Electrodynamic Mission," Space Tethers for Science in the space Station ERA, Società Italiana di Fisca, Conference Proceedings No. 14, 1988.

[5] A. D. Johnstone, S. J. Kellock, A. J. Coates, M. F. Smith, T. Booker, and J. D. Winningham, IEE Trans. Nucl. Sci. NS-32, 139 (1985).

[6] F. R. Paolini and G. C. Theodoridus, Rev. Sci. Instrum. 38, 579 (1967).

[7] G. C. Theodoridus and F. R. Paolini, Rev. Sci. Instrum. 40, 621 (1969).

[8] S. Nishigaki and S. Kanai, Rev. Sci. Instrum. 57, 225 (1986).

[9] F. J. Marshall, D. A. Hardy, A. Huber, J. Pantazis, J. McGarity, E. Holeman, and J. D. Winningham, Rev. Sci. Instrum. 57, 229 (1986).

Appendix II "Shuttle Potential and Return Electron Experiment"

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The Shuttle Potential and Return Electron Experiment

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Abstract

The Shuttle Potential and Return Electron Experiment (SPREE) is a plasma diagnostic system that was flown in the Space Shuttle payload bay as part of the joint NASA/Italy/U.S. Air Force Tethered Satellite System 1 (TSS-1). The SPREE measures energy and angular characteristics of ion and electron particle flux and processes that data to identify wave-particle interactions (WPI). The data SPREE collects are integral in quantifying the electrodynamic behavior of TSS-1. The system consists of a multiple microprocessor based Data Processing Unit (DPU), a pair of nested triquadraspherical electrostatic analyzers mounted on rotary platforms, a space particle correlator system, and two space qualified high density (> 2 Gigabytes) data recorders. The electrostatic analyzers measure both electrons and ions simultaneously over an angular fan of 100°, segmented into ten 10° wide zones. A programmable sweep high voltage power supply provides 32 logarithmically spaced deflection voltages to cover a 10 eV to 10 keV energy range. The rotary tables allow the analyzers to view all angles out of the Shuttle bay. The analyzers operate over a dynamic range from 10^3 to 10^{12} particles /cm² in particle flux and 0-10 MHz in WPI. The SPREE is capable of operating in an environment that may consist of high pressure surges (>2 x10^{-4} Torr), active electron beams, and RF bursts. Under these conditions, the SPREE DPU uses an on-board algorithm to assess and report the charge level of the Shuttle with respect to the local plasma.

Introduction

The Shuttle Potential and Return Electron Experiment (SPREE) was developed as part of the instrumentation for the Tethered Satellite System (TSS-1). It was flown on the Space Shuttle (STS-46) in August 1992. The TSS-1 system consisted of a deployable satellite and a suite of instrumentation mounted in the Shuttle bay and on the satellite. Using an electrically conductive tether, the satellite was intended to be deployed to a distance of approximately 20 kilometers from the Shuttle. As the conductive tether passed through the earth's magnetic field, an emf was induced that tends to drive a current between the satellite and the Shuttle. This current, when permitted to flow, passes through either load resistors to Shuttle ground or to electron guns that emit the collected

current[2,3,4]. Any charge imbalance resulting from either of these configurations will result in charging of the Shuttle, which SPREE measured and reported.

The electron beam system on TSS-1 can emit currents up to 500 mA at voltages up to several kilovolts when the satellite is fully deployed. Even the partial deployment at 256 meters achieved about 50 volts and 15 mA current. A multi-kilowatt beam may interact with the ambient plasma through wave particle interactions (WPI), producing heating of the plasma as well as other perturbations. The orientation of the local magnetic field or the development of a sheath potential around the Shuttle may cause a significant portion of the electron beam to be returned to the Shuttle. We observed occasional electron fluxes that were many orders of magnitude larger than the flux provided by the local plasma. These return current drove the Shuttle ground negatively with respect to the ambient plasma.

The specific goals of SPREE for the TSS-1 mission were:

- Monitor the ground potential of the Shuttle during all phases of the TSS-1 mission,
- Determine the return current to the Shuttle from the operation of the TSS-1 electron beam systems, and
- Specify the energy and angle in the measured particle distribution function at which coherent wave particle interactions or other periodic behavior occurred during operation of the TSS-1.

The SPREE system builds on detector and DPU technology developed for the Ampte, Giotto and CRRES satellites. The SPREE system consists of four principal subsystems:

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[2]P. R. Williamson, P. M. Banks, and W. J. Raitt, "Shuttle Electrodynamic Tether System," Space Tethers for Science in the Space Station ERA, Società Italiana di Fisca, Conference Proceedings, 14, 1988

[3]C. Bonifazi, P. Musi, G. Cirri, and M. Cavallini, "TSS Core Equipment: A High Perveance Electron Generator for the Electrodynamic Mission," Space Tethers for Science in the Space Station ERA, Società Italiana di Fisca, Conference Proceedings, 14, 1988

[4]M. R. Oberhardt and D. A. Hardy, "Shuttle Potential and Return Electron Experiment (SPREE)," presented at Third International Conference on Tethers in Space, 17-19 May 1989

- A pair of nested triquadraspherical electrostatic analyzers (ESA) mounted on rotary tables to measure the flux of electrons and ions from 10 eV to 10 keV and over a look angle of 2π solid angle.
- a Space Particle Correlator (SPACE) to measure modulations in the electron and ion flux.
- a pair of high density digital tape recorders.
- a multi-microprocessor based DPU designed to control the other subsystems, to perform on-orbit, real time determination of the Shuttle potential and to handle command, power, and telemetry interfaces to the Shuttle.

We describe details of the design and operation of the subsystems below.

I. Electrostatic Analyzer and Rotary Table Subsystem

A pair of nested triquadraspherical detectors mounted on rotary tables detect ions and electrons. The sensor and rotary table consist of five components: a) the particle deflection system, b) the microchannel plate (MCP) and anode assembly, c) the output pulse amplifier, d) the high voltage power supply, and e) the rotary table. The SPREE Electrostatic Analyzer (ESA) is described in another article.[5]

The SPREE sensors are mounted on rotating tables that sweep each ESA through 180° of azimuth. The ESA viewing fans are perpendicular to the azimuthal plane and extend ten degrees past the axis of rotation of the rotary tables. Figure 1 shows the sensor mounted on a rotary table assembly. Two of these assemblies mount back-to-back in the Shuttle payload bay to achieve a full 2π field-of-view.

Normal operation synchronizes the tables such that the ESAs view in opposite directions (180° apart) and sweep through 180° of azimuth before reversing and repeating their scan in the opposite direction. They rotate at 6° per second. A ground command can park the motors at a fixed azimuth if real time conditions indicate a preferred viewing direction out of the Shuttle payload bay.

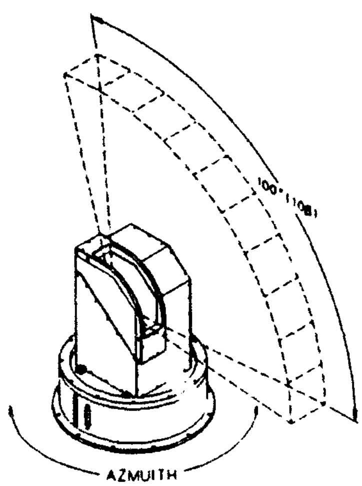

Figure 1

SPREE Sensor Field-of-View Mounted on the Rotary Table

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[5] J. O. McGarity, A. Huber, J. Pantazis, M. R. Oberhardt, D. A. Hardy, and W. E. Slutter, "A compact ion/electron analyzer for spaceflight or laboratory use," Rev. Sci. Instrum. 63, Mar (1992)

Motor and Motor Control

The drive unit for the rotary table is a Densei stepper motor, model P5J-U12S that was conditioned for thermal vacuum operation. The motor drive circuit was tuned to the Densei motor winding characteristics and the motor driving frequency to minimize power dissipation. A timing circuit limits the stepping impulse period applied to a winding. The controller removes current from all the motor windings if stepping pulses stop.

Harmonic Drive and Housing

A harmonic drive transmission built by Harmonic Drive[6] amplifies the motor output torque to the required level. This device consists of a pair of concentrically mounted gears. The outer gear teeth face inward and are rigid. The inner gear teeth face outward and are part of a stainless steel sleeve that is thin enough to be flexible. The inner gear has two teeth fewer than the outer gear. An eccentrically machined bearing presses into the flexible inner sleeve and the eccentricity causes the sleeve to distort and engage the outer system for the entire circumference except for two small areas that are 180° apart. A drive shaft rotates the eccentric bearing causing the un-engaged gear region to rotate about the drive shaft. Since the inner gear has fewer teeth than the exterior gear, this rotation causes the outer gear to rotate about the inner sleeve. The difference between the number of teeth contained on each of the two gears determines the ratio of rotation between the outer and inner gears. SPREE uses a model PCR-3C-1 with a 100:1 gear ratio. We cleaned and conditioned the harmonic drive transmission for vacuum compatibility.

II. Space Particle Correlator Experiment (SPACE)

Wave-particle interactions are important as they are one of the few processes by which energy exchanges occur between different particle populations in a collisionless plasma. The mechanism responsible for damping in a collisionless plasma is the interaction of the particles with electric field components of the wave. This occurs when the particle velocity is approximately that of the phase velocity of the wave, resulting in a resonance. This condition exists at Shuttle altitudes. Part of the SPREE is the Space Particle Correlator Experiment (SPACE) which examines the unprocessed count rate data from the electrostatic analyzers to determine the wave-particle interactions.

Two consequences can result from charged particles being in velocity resonance with waves. Particle energy can transfer to the waves resulting in wave amplitude growth and particle deceleration, or wave energy can transfer to the particles resulting in particle acceleration and wave damping. In either case, charged particles in velocity resonance will become phase bunched with the wave. This is observable as fluxes of particles at the resonant velocity (energy level) being modulated in time at the wave frequency. Measurements of these particle modulations as a function of frequency, energy level, and

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[6]Harmonic Drive, 51 Armory Street, Wakefield, MA 01880

particle direction of motion, allow identification of those regions of particle velocity space contributing to wave growth and wave damping. SPACE performs this type of analysis on the SPREE data set.

SPACE is a microprocessor and microcontroller based signal processing unit. Figure 2 is a block diagram showing the SPREE DPU/SPACE configuration. SPACE takes as its principal input the raw pulse stream coming from the 40 preamplifiers connected to the forty anodes. A 20 MHz clock used by the microprocessor determines the occurrence time of each pulse. This timing information identifies high frequency bunching of particles. Three separate methods discriminate frequency modulations of the observed particle fluxes. One of these methods is cross-correlation, briefly described below.

Correlators allow for the detection of reflected particle beams. The SPACE receives synchronization signals from the Deployer Core Equipment (DCORE)[2] and the Shuttle Electrodynamic Tether System (SETS)[1]. The DCORE signals indicate the on/off cycle of the DCORE electron guns and the SETS signals indicate the Fast Pulsed Electron Gun (FPEG) pulses. The SPACE uses these signals to cross-correlate electron gun activity with measured particles.

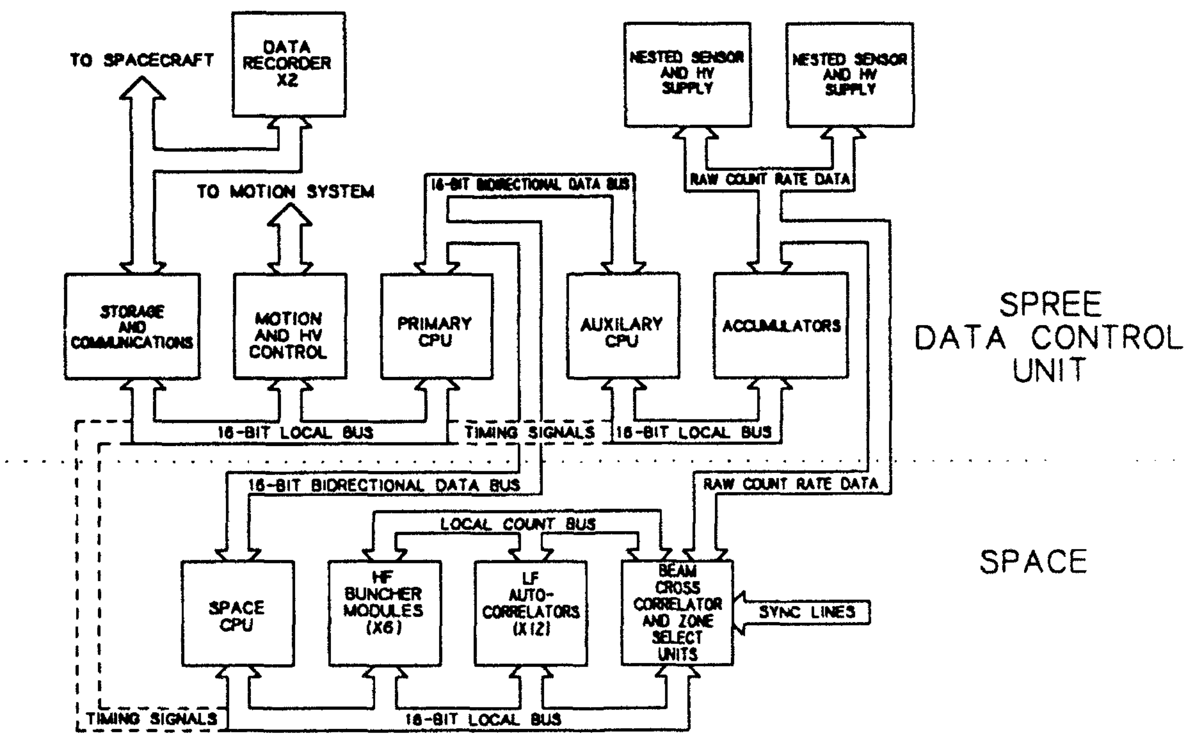

Figure 2 -- SPREE Data Processing Unit Block Diagram

High Frequency Buncher Mode

In the 1-10 MHz frequency range, there are a number of frequencies at which a wave-particle interaction should occur. These frequencies are the local electron gyrofrequency, ~1.4 MHz, which varies with orbital location, and the local upper hybrid frequency, 1-7 MHz, which varies with local neutral and electron densities. These high frequency modulations superimpose on counting rates that can be of the order of 100,000 counts per second or less. A one bit "buncher" mode of correlation deconvolves this high frequency data from the counting statistics. A 20 MHz clock measures the time of arrival between successive electrons. A histogram of the number of measured separations as a function of separation units (50 nS) accumulates over a time. This is the equivalent of averaging many one bit correlation functions with each using only two bits set. Note that this technique has successfully identified modulations at MHz frequencies present in the natural auroral beams above auroral arcs.[7]

The high frequency range is subdivided into three frequency bands, 0-.625 MHz, 0-2.5 MHz, and 0-10 MHz. This accommodates the expected wide range of counting rates and expected phenomenology. Selections of various multiples of the separation units create a histogram. Six electron zones are correlated at a time. Complete processing of all 20 electron zones and all three of the frequency bandwidths occurs every nine minutes. Local reflections from the plasma sheath or wake and beam returns are resolved to within 100 nanoseconds and ~ 1 meter, using this technique.

Low Frequency Autocorrelation Function

SPACE performs low frequency autocorrelations in the frequency band from 0-10 kHz. At the lower hybrid frequency (<10 kHz) and the ion gyrofrequencies (<1 kHz), naturally occurring modulations are expected. Beam-induced plasma heating can be measured in the electron and ion population.

Twelve 80C31 microcontroller units (MCU) perform twelve independent simultaneous autocorrelations. A commutation system allows these MCUs to process all forty zones (20 ion and 20 electron) using three different bandwidths, 0-10 kHz, 0-5 kHz, and 0-1.3 kHz. The modulation detection efficiency for the system ranges from 72% (for the 10 kHz bandwidth) to 99% (for the 5 and 1.3 kHz bands). A dedicated 80C86 controls the 80C31 MCUs and supervises all the SPACE operations. A "mail box" scheme communicates with the rest of the SPREE through shared memory. The low frequency autocorrelation technique measures particle reflections within 100 microseconds to a spatial resolution of ~1 km. Mirror point bounce reflections were measured, for example.

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[7]M. P. Gough, P. J. Christiansen, and K. Wilhelm, "Auroral Beam-Plasma Interactions: Particle Correlator Investigations", J. Geophys. Res. 95, 12287, 1990

Beam Cross Correlation

Included in the TSS-1 experiments are Shuttle-mounted electron guns used to inject into the local ionospheric plasma the current collected via the tether and Shuttle-mounted electron guns that operate on an independent power supply, collecting electrons for injection through the Shuttle ground. The first pair of guns are part of DCORE[2] and the second pair are part of SETS[1]. The SETS electron guns, the FPEGs, can modulate at kilohertz frequencies that will effectively "tag" the beam electrons with this artificial frequency. Depending on frequency and plasma conditions, the modulated beam may trigger natural emissions. This known frequency signature identifies any portion of the SETS electron beams returning to the shuttle. Furthermore, the correlator identifies any beam electrons that have undergone acceleration or deceleration, or ambient electrons that have interacted with the beam modulation. We performed experiments with the FPEG modulating its beam in a manner to allow SPACE to observe mirror point bounce reflections and reflections from the Orbiter sheath and wake.

Both electron gun systems operating during the TSS-1 mission provide synchronization signals to the SPACE, indicating gun emission. If more than one gun is emitting, the beam correlator selects one gun with which to perform its correlation. For each ESA zone, analyzed counts are binned into two counters depending on whether an electron gun is instantaneously on or off. A separate count of a stable oscillator provides a measure of the total time spent on or off. If there is no significant modulation present in the accumulated counts, the variation of these two sums fits Poisson statistics after accounting for the total "on" and "off" times. This technique gives a direct measure of the significance of particle modulation at the beam modulation frequency.

Neural Network Algorithm

Due to the limitations in the real-time downlink bandwidth, only a select portion of the SPACE data are in the SPREE downlink telemetry, with the bulk of the SPACE data stored in the SPREE data recorders on-board. Since there is command and control capability to modify the experiment configuration, some indication of the significance of the SPACE correlations is useful in real-time to optimize the overall TSS-1 mission to achieve the maximum science return. A highly processed real-time SPACE data set provides rapid insight into the experiment performance.

We use a neural network to develop this rapid and succinct SPACE data set for the real-time data stream. The data needed to contain some indication of the nature of the data being recorded on board as well as verification of the SPACE operations. A personal computer (PC) based "intelligent data analyst" used a neural network to form a pattern recognition system. The network data were prelearned by the ground based PC in about three hours of processing. This resulted in an algorithm that SPACE could apply to a data set in a matter of milliseconds. The algorithm consists of a look-up table stored in ROM and used during flight operations to provide data quality assessment in real time. The

algorithm searches for ninety-six patterns. Sixty-four wave patterns correspond to frequencies from the lowest to highest that can be studied in an autocorrelation function. Thirty-two radar patterns correspond to delayed secondary peaks ranging from zero to maximum delay measurable in an autocorrelation function.

The return real time data from SPREE during the TSS-1 flight indicated that this system was functioning and very useful.

III. Recorder System

The real-time telemetry link could not support the high data rate generated by the SPREE. Therefore, we used a high density data recorder. We selected an Exabyte Model 8200, 8 mm cartridge recorder. This unit is a magnetic tape recorder using helical scanning technology with a capacity of approximately two Gigabytes/cassette. SPREE flies two units to provide sufficient capacity and redundancy.

Several changes and modifications were necessary to adapt this commercial technology to spaceflight. A hermetic container maintained pressure and humidity for the tape recorder. We mounted the tape transport mechanism on vibration isolators so that it withstands the launch and recovery environment. All the electronics boards were mechanically reinforced to provide structural support. The reinforcing also provides thermal paths for heat dissipation during operations. A heater was installed to allow startup from cold conditions. Cabling was replaced or reinforced. An added interface board handles communications and control.

The 8 mm recorder came equipped with a Small Computer System Interface (SCSI). The timing and protocol for the SCSI were inefficient in the handling of the real-time data stream from the SPREE. An asynchronous interface modeled on the MIL-STD-1553B protocol handles communications between the recorders and the Data Processing Unit for SPREE. A microprocessor directed bridge controller manages the data flow and operates the SCSI protocol, timing, and error handling. A data buffering system and a burst mode for writing to tape optimizes the tape writing process.

The bridge controller software handles all the status, timing, and error conditions that occur and the SCSI protocol requirements. It can rewrite blocks of data if a tape error occurs. It maintains a remaining tape counter, monitors beginning and ending of tape channels and performs appropriate initialization and termination procedures for the tape recorder. It keeps count of errors and rewrite attempts.

The bridge controller also monitors the tape recorder environment. It receives pressure information from an internal transducer. It monitors the temperature of the recorder housing and the electronics and controls a heater to insure the recorder temperature stays within safe limits. It can remove power from the recorder if conditions exceed preset limits.

The bridge controller software operates the handshake protocol between the recorder and the SPREE Digital Processing Unit. It buffers experiment data until a

suitable block size accumulates to burst to the recorder. The system for SPREE records 16 blocks per second of 1024 bytes each.

This recorder system collected more than 4 Gigabytes of data during the 40 hour mission.

IV. Digital Processing Unit

The Digital Processing Unit (DPU) is responsible for the coordination and control of the several isolated tasks required for the operation of SPREE. These include the handling of the incoming data from SPACE and the ESAs, the formatting and transfer of two separate outgoing data streams, the interpretation and execution of commands from both the ground and the Shuttle aft flight deck, the monitoring and recording of instrument status and health, the control of the motion of the rotary tables, the processing of raw ESA data to determine Shuttle charging levels, and control of the SPACE and tape recorder interfaces.

To accomplish all these tasks in real-time, on-orbit, required the use of three 80C86 microprocessors in parallel sharing a common bus. (Please reference Figure 2.) One processor dealt with the outside interface protocol for communications with the Shuttle Smart Flexible Multiplexer/Demultiplexer (SFMDM) for command and real time telemetry. It also controlled the tape recorder operations. Another processor oversaw the experiment operations, controlling the rotary tables, stepping the energy selection of the ESAs, accumulating the raw count rates from the ESAs, and processing the data through the charging algorithm mentioned above. The third 80C86 supervised the particle correlator operation. Thermal control concerns required power dissipation to be minimal. We therefore limited the microprocessor clock speed and use low power CMOS technology.

Besides these input/output functions, the DPU time tags the data stream fed to the on-board recorders. It synchronizes the experiment to the SFMDM operation and marks the data stream with a time code coming from the Shuttle Payload Timing Buffer. If the SFMDM signal is not present, the DPU continues on an internal clock that permits the experiment to operate and records data even without the SFMDM handshake. If the SFMDM handshake is intermittent, the DPU will attempt to resynchronize to it. The DPU also interleaves mode and status information into the data stream to assist data analysis.

Charge Detection Algorithm

The algorithm calculating the Shuttle's negative potential with respect to the ambient plasma uses data collected by the 20 ion zones in the SPREE ESAs. Ion spectra are used because a negative charging event should produce a peak in the ion energy spectrum resulting from the acceleration of the ambient thermal plasma toward the charged surface. Because of the TSS-1 flight configuration, a negative potential occurs during TSS-1 deployed operations if the electrons emitted by the guns do not escape or if

tether current is shunted to Shuttle ground. A simple algorithm could search all the elevation zones for the energy with the greatest count and assume that it represents the potential. However, multiple peaks, background noise, and saturation could deceive such a routine. A complete program must be able to recognize situations that do not indicate charging. The SPREE algorithm uses several functions to process data in a manner accounting for the complexities in the ion spectra, producing a potential determination with an associated confidence factor.

Once per second, the auxiliary processor begins a new algorithm routine. A default table that can be modified by ground command contains parameter values that alter the algorithm performance when scanning the data. The processor acquires 20 complete ion spectra from the analyzers during a single high voltage sweep. The data are scanned for possible saturation conditions and then filtered. Eliminating all but the important peaks in count rate compresses the information. Other points that are dismissed are those that exceed the saturation level, or are less than the threshold. The largest remaining value is called the primary peak, the next largest the secondary peak. The azimuth, elevation, and count rates for these peaks are recorded. An alternative potential determination may be made based on the maximum frequency a peak is measured in a given energy channel. Ground commanding offers us the opportunity to vary the potential selection technique between the peak count and frequency in energy search.

The algorithm functions by accumulating all the data that the sensors produce and sifting that information down to an energy/angle/intensity matrix. The algorithm records as many high voltage sweeps as are performed in one second, one sweep if in slow mode and eight sweeps if in fast mode. A tally of all sweeps is analyzed and a report is generated. The report includes information on the peak flux, azimuth and elevation where the peak was detected, the flux in the energy bins adjacent to the peak, ion and electron spectra for the zone that contained the peak, the ion sum spectra from both ESAs, and the ESA that yielded the potential determination.

A decision making logic tree derives a confidence factor from the stored data. The weighted confidence factor displays on a scale from 0% to 100% and represents the algorithm's best estimate of the validity of the charge potential reported. The confidence algorithm assesses the following:

- The number of analyzers providing data,
- Rotary table position,
- Peak detection,
- Whether the peak was determined by high count rate or frequency of a given energy response,
- Magnitude of the primary peak compared to the secondary peak,
- Limits on expected potential given TSS-1 parameters,
- The FWHM of the peak,
- The number and location of saturated measurements, and
- The extent of masking of certain channels.

The confidence factor occurs at the end of the potential determination report and transfers to the primary processor through a memory mapped mail box.

Unpredictable plasma interactions during the TSS-1 experiments pose challenges to a successful algorithm. Various parameters of the charging algorithm could require modification on-orbit to properly determine charging events. Uplink capability to the microprocessor code allows altering these key variables. SPREE has been pre-programmed with default parameters derived from plasma calibration tests conducted during qualification testing. Some of the algorithm parameters included in the uplink capability are:

- limits on the valid maximum flux,
- sensor saturation levels,
- minimum threshold necessary for a valid peak,
- masks on noisy or malfunctioning channels, and
- selection of potential reporting based on the highest count rate or on the most frequent energy peak.

V. Conclusion

The TSS-1 mission presented a unique opportunity to determine the electrodynamic interactions between high-powered, large space systems and the ambient environment. The SPREE provided not only insight into the electrodynamic behavior of a system such as TSS-1, but also demonstrated the use of new technologies in particle detection, data collection and storage in space, and in-situ data analysis. As such, the SPREE was an integral part of the TSS-1 mission and greatly augmented the scientific return of the mission.

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